LATTE – Linking Acoustic Tests and Tagging Using Statistical Estimation

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LONG-TERM GOALS

The goal of this project is to improve our ability to predict the behavioral response of beaked whales to mid-frequency active (MFA) sonar, by making better use of data already collected, or being collected as part of other projects.

OBJECTIVES

We aim to construct and fit mathematical models of the diving behavior of beaked whales, and their response to MFA sonar. These models will be parameterized by fitting them simultaneously to three sources of data: (1) short-term, high fidelity tagging studies on individual whales (some of which comes from animals exposed to acoustic stimuli); (2) medium-term satellite tagging studies of individual whales (some of which we hope will come from data collected during navy exercises); and (3) long-term passive acoustic monitoring from bottom-mounted hydrophones (much of which comes from data collected during navy exercises). All data will come from the Atlantic Undersea Test and Evaluation Center (AUTEC), Bahamas, and the surrounding area. Hence our models and predictions

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will be directly applicable to animals in that area, although we hope they will be of more general relevance.

Outputs of the model are designed to be compatible with risk evaluation and mitigation tools and models developed under other ONR initiatives, such as Effects of Sound on the Marine Environment (ESME) and Population Consequences of Acoustic Disturbance (PCADS). Hence, the model will:

(1) predict the behavioral responses of individual beaked whales to MFA sonar;

(2) provide sufficient information to assess the level of "take" that is likely as a result of sonar operations;

(3) provide sufficient information to allow the energetic costs of disturbance by MFA to be estimated; (4) provide a modeling framework within which information concerning behavioral responses of beaked whales can be interpreted.

APPROACH

The overall modeling framework we are adopting is called a "state-space model". Such models describe the evolution of two stochastic time series in discrete time: (1) a set of true but unknown, states, which in our case are the positions of diving whales, and (2) a set of noisy observations related to these states, which in our case are the three sources of data described above. A "process model" describes how the states change through time, and a set of "observation models" describe how the observations link to the states. Here, the process model is a stochastic, discrete-time model for the movement of individual diving beaked whales, and their group dynamics.

The work of the project is divided into four tasks, each divided into subtasks, as described in the project proposal.

- Task 1 involves specifying the process model; this is largely the responsibility of the main postdoctoral research fellow working on this project, Dr. Tiago Marques, in collaboration with Thomas, Boyd and Harwood.
- Task 2 involves developing the formal fitting procedures required to fit the state-space model to the three sources of data. Computer-intensive Bayesian statistical methods will be used. Such methods have been the subject of enormous growth in research activity recently; nevertheless fitting complex movement models to data at such a range of temporal scales is very challenging, and considerable effort is being devoted to algorithm development. This is being undertaken by Marques and Thomas.
- Task 3 involves processing the data required for input to the model. A large amount of acoustic and tag data are potentially available, but much of it requires extraction and processing to bring it into a form that's useful for this project. This is being undertaken by staff at NUWC, under the direction of Moretti.
- Task 4 involves project supervision and coordination. This includes monthly tele-conference progress meetings, as well as face-to-face meetings at least once a year, and is coordinated by project manager Dr. Catriona Harris at St Andrews.

WORK COMPLETED

The project started in April 2010. We have been able to take advantage of travel opportunities largely funded under other projects to meet face-to-face four times, most recently at Mt. Hood during the 2011 DCL workshop. In addition, we have been having regular tele-meetings to discuss progress.

Under Task 1, we have completed a review of models for marine mammal diving behavior. A working document was created containing a compendium of potential modeling approaches and models, with associated references. One conclusion of this review is that there has been relatively little effort to model dive data, with most work to date being implemented over 2-dimentional (2D) data. Further, most of the current work in 2D data as dealt with relatively simple, proof-of-concept data sets. There are also several instances of models used for simulation. We are now focusing on extending these models to the current context. We are developing a hierarchical model that considers group movement, embedded within a model to account for individual animal movement. This raises an issue of lack of data, since there are no instances of simultaneously tagged animals of the target species. We are therefore using a mixture of expert opinion and data from other species with simultaneous tags to construct this part of the model – clearly the acoustic footprint of a diving group will be extremely dependent on that behavior.

For Task 2, we have extended the analysis of data from Submarine Commander Course (SCC) exercises that were held at the US Navy AUTEC range in May 2007 and 2008, as well as simple initial analysis of digital tag (DTAG) data collected during August and September 2007. This represents a relatively tractable way to make initial inferences about large-scale patterns in diving behavior associated with navy activities. Our initial work on the SSCs has been published (McCarthy et al. 2011), and we are now extending this to look at finer scale patterns of acoustic behavior (see Results). We are now beginning initial fitting of simplified movement models to the DTAG data with Kalman filtering approaches, and will move on to more complex models and fitting methods depending on our results.

Under the Task 3, SCC and DTAG data have been processed and provided; further data processing is now under way to quantify the dose (of sound exposure) to which animals were subjected during the SCC exercise. This will allow us to construct a dose-response curve, where the response is the number of diving groups per unit time. In doing this, we will need to account for the fact that periods of high range activity induce responses over a time scale of days, and hence received dose over the preceeding few hours cannot be used alone to predict vocal activitiy.

As mentioned above, project coordination (Task 4) has been greatly facilitated by opportunities for face-to-face meetings. We have also been able to coordinate with other projects, mentioned under "Related projects", below.

RESULTS

The main results so far relate to the SCC data analysis, from which it seems clear that beaked whales either significantly lower their vocal activity or leave the range area during large-scale naval exercise periods (McCarthy et al. 2011, based on 2007 and 2008 data). We are now drilling into the 2009 SCC data in more spatial and temporal detail. During the exercises, it seems possible to distinguish differences in acoustic behavior between periods of very high ship activity vs. ship redeployment periods, with cetacean activity being higher during the later ones (Figure 1).

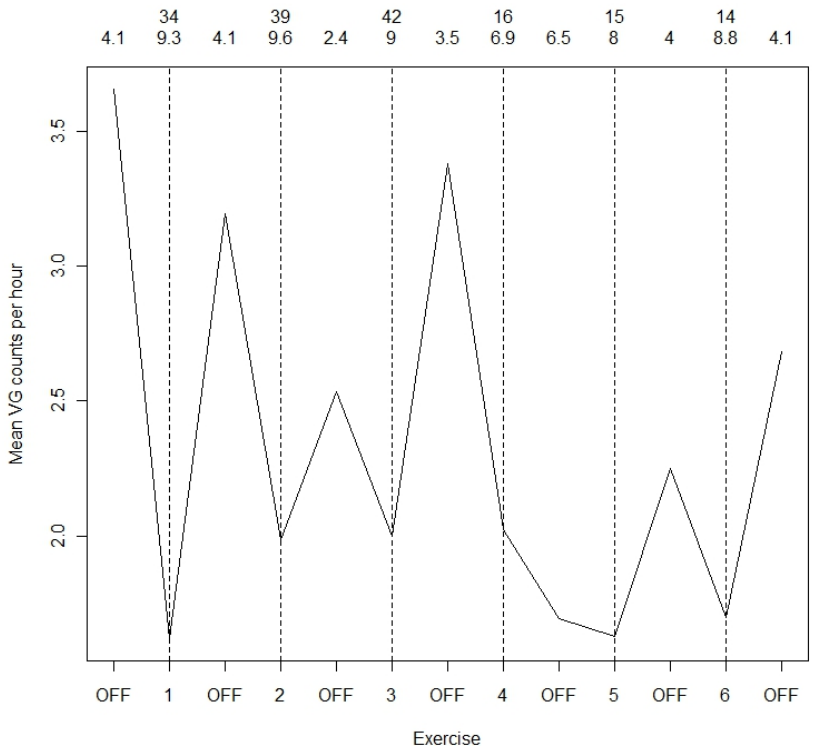

Figure 1 – Mean number of <u>Mesoplodon densirostris</u> vocal groups detected (y axis) as a function of whether there is or not a "scenario" (mini exercise) taking place (scenario number along the x axis). There are two rows of numbers on top of the plot: the first is the total number of sonar events during the corresponding scenario and the second is the number of hours the corresponding period lasted. There are a lower number of groups vocalizing in periods where scenarios are taking place. Data corresponds to 2009 SCC exercise, from 17th April to 20th June 2009.

Another interesting result for the exploratory analysis of the SCC data is that the activity of vocal groups seems to be almost constant during the day, with perhaps a decrease in activity near sunrise and sunset (Figure 2). This will need to be accounted for when interpreting activity data.

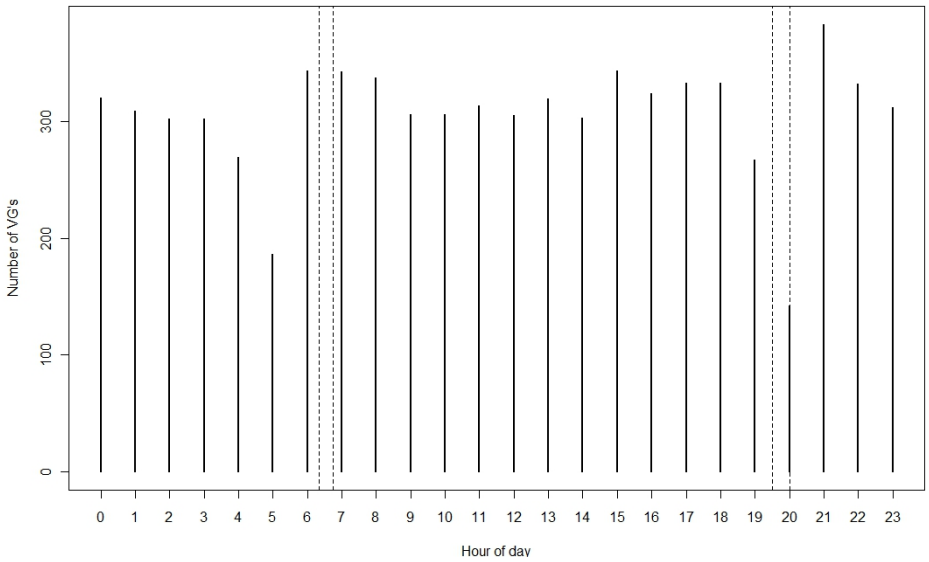

Figure 2 – Number of <u>Mesoplodon densirostris</u> vocal groups starting as a function of the hour of day (local time). Dashed vertical lines represent range of sunrise and sunset hours during the study period. The lower activity periods seem to be closely associated with dusk and dawn periods. Data corresponds to 2009 SCC exercise, from 17th April to 20th June 2009.

IMPACT/APPLICATIONS

Determining and mitigating the effect of mid-frequency active sonar on marine mammals is a key goal for the US Navy in complying with marine mammal protection requirements. The proposed research is aimed at developing tools to facilitate this. Although current behavioral response experiments provide key information, it seems unlikely that they will ever yield large enough samples to provide a complete picture of the response of vulnerable species to sonar. By combining information from these rare, directed studies with the large amount of opportunistic data available from exercises on instrumented testing ranges, obtaining the required information about animal response becomes feasible. This information could possibly be used to avoid future mass strandings, and can certainly be used to better estimate the number of animals exposed to high levels of sound (likely fewer than currently assumed).

RELATED PROJECTS

- Behavioral Response Study – an experimental approach to determining the behavioral response of marine mammal species to MFA sonar that provided the motivation for, and much of the data for, the current study.
- M3R program – the passive acoustics monitoring algorithms and tools development program at NUWC that has facilitated much of the data processing work used in the current project.

- DECAF – a project developing methods for density estimation from fixed acoustic sensors that provided the initial monitoring tools being further developed in this project.
- PCAD – a project to implement the population consequences of acoustic disturbance model to four case study species including beaked whales at AUTEC. Output from the LATTE project will provide useful input into PCAD-type models, even if the outputs come too late for direct use in the current PCAD project.
- The way they move – a research project at the University of St Andrews developing algorithms for fitting state-space models to terrestrial animal tag data; the current project is leveraging many of the findings from this project.

PUBLICATIONS

McCarthy, E., D. Moretti, L. Thomas, N. DiMarzio, R. Morrissey, S. Jarvis, J. Ward, A. Izzi, A. Dilley. 2011. Changes in spatial and temporal distribution and vocal behavior of Blainville's beaked whales (*Mesoplodon densirostris*) during multi-ship exercises with mid-frequency sonar. Marine Mammal Science 27(3): E206-E226. [published, refereed]